Capacity Building and the Development of Tools For Enhanced Utilization of Climate Information and Prediction Products for the Planning and Management of Hydropower Resources in Kenya

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LIST OF ACRONYMS USED

AN-NN-BN	-	*Above Normal-Near Normal-Below Normal*
COF	-	*Climate Outlook Fora*
COTU	-	*Central Organization of Trade Unions*
DMCN	-	*Drought Monitoring Center, Nairobi*
ENSO	-	*El-Niño/Southern Oscillation*
ERB	-	*Electricity Regulatory Board*
GDP	-	*Gross Domestic Product*
GHA	-	*Greater Horn of Africa*
GHACOF	-	*Greater Horn of Africa Climate Outlook Fora*
IPP	-	*Independent Power Producers*
IRI	-	*International Research Institute*
JICA	-	*Japan International Cooperation Agency*
KAM	-	*Kenya Association of Manufacturers*
KenGen	-	*Kenya electricity Generating Company*
KMD	-	*Kenya Meteorological Department*
KPLC	-	*Kenya Power and Lighting Company*
KV	-	*Kilo-Volts*
KWh	-	*Kilowatt hours*
LLO	-	*Low Level Outlet*
MAM	-	*March-April-May*
MoE	-	*Ministry of Energy*
MOL	-	*Minimum Operating Level*
MoW	-	*Ministry of Works*
MW	-	*Megawatts*
MS	-	*Mean Sum Square.*
MVA	-	*MegaVolt-Ampere*
OND	-	*October- November-December*
QBO	-	*Quasi-Biennial Oscillation*
REP	-	*Rural Electrification Project.*
TARDA	-	*Tana and Athi River Development Authority*
SS	-	*Sum of Squares*
SSTs	-	*Sea Surface Temperatures*
UEB	-	*Uganda Electricity Board.*

SUMMARY

Kenya has in the recent past experienced two major extreme climate events, namely, the 1997/98 El-Niño related floods and the 1999-2000 La Niña related drought both of which led to severe socio-economic impacts in the country. Inadequate rainfall during the prolonged 1999-2000 drought led to deficient water and electrical power supply in the country consequently bringing the start of serious power rationing throughout the country. Kenya's economy performed poorly during the drought period in which all sectors of the economy were adversely affected. The enormous losses related with these two events is a clear indication that there is need to factor in climate information and prediction products into the planning and decision-making processes within the energy sector if sustainable development can be achieved.

The overall objective of this study is to sensitize and build capacity of the hydropower experts in utilizing climate information and prediction products in the planning and management of the hydropower resource. This is to enable the sector to be in a good position to adapt and/or mitigate against well in advance any negative impacts related to climate anomalies or fluctuations on the resource. The other specific objectives included the following assessing the level of usage of climate information and prediction products within the sector the context of timings, understandability, accuracy and perceived relevance.

The study also investigated the teleconnections between the anomalies of river flows and the global ocean Sea Surface Temperatures (SSTs), QBO, ENSO as well as Zonal Gradients (ZG) in order to develop predictive models for seasonal river flow anomalies and hence power generation. An attempt was also made to try and develop a methodology for translating the Tercile forecasts into ranges of values of river flows in the respective hydropower catchment areas and to document the results into a format that can easily be understood by the experts in the hydropower sector.

The results of this study have clearly demonstrated that climate information and prediction products are in fact important tools with regard to the planning and management process of the hydroelectric power generation in Kenya and that this sector is taking very keen interest in the seasonal climate forecasts and product updates regularly delivered by DMCN and KMD for the overall planning of the dam storage. The project was able to achieve its overall objective by ensuring that the capacity of the experts within the hydropower sector was adequately built through various ways and at the moment they are able to appreciate the seasonal forecasts presented in terms of probabilistic forecasts as well as the analogue techniques are also being tried for planning purposes.

The study was able to show that the global SST anomalies have excellent predictive capabilities for streamflow forecasting for the upper Tana river catchment at seasonal time scales and that the predictions for the MAM, JJA and SOND 2003 seasonal inflows into Masinga and Kamburu Dams gave very high skills of more than 80%.

The study recommends that more work needs to be done in further improving the streamflow forecasting models and that DMCN and KMD needs to continue working in partnership with the Hydropower sector in order to come up with tailored made products suitable for this sector.

1.0 INTRODUCTION

Kenya have in the recent past experienced two major extreme climate events that led to severe socio-economic impacts such loss of life and property, damage to infrastructure, mass migration of animals and society, disruption of power supply, water shortage, famine among many other socio-economic miseries. Good examples of the potential hazards of the extreme climate events were demonstrated by the 1997/98 El-Niño floods that were immediately followed by the 1999-2000 La Niña related drought, the worst in 50 years.

Inadequate rainfall during the prolonged 1999-2000 drought and the delay in the implementation of some of the planned power projects led to a serious shortage in the supply of electricity in Kenya. The consequence of this was the start of rationing power in September 1999 by the Kenya Power and Lighting Company. By June 2000, electricity generation in Kenya had fallen by 40%, prompting the Kenyan government to announce more stringent power rationing measures where residential power was cut from sunrise to sundown and industrial power was stopped from sunset to sunrise.

All economic activities such as planning, water resources and land use management, transportation and storage of products are dependent on weather and climatic conditions. The Kenyan economy performed poorly during the drought period in which the economic growth, measured by the Gross Domestic Product, GDP, declined by 0.3% in 2000. The weak economic performance was mainly attributable to the prolonged drought that adversely all sectors of the economy including reduced generation of electricity from hydro sources.

The energy sales by KenGen Company during the drought period dropped by 46% while the operating costs shot up by Ksh.613 million. This is attributed to increase in fuel expenditure on enhanced thermal generation to make up for reduced generation from hydro sources. It is estimated that the energy crisis generated a loss to the economy of nearly *US$100 million* per month. It is therefore necessary to factor climate information and prediction products in the planning and decision-making processes account if sustainable development of socio-economic activities is to be achieved.

2.0 JUSTIFICATION

Energy is an inevitable and essential input required in all socio-economic development activities. Kenya aspires to emerge as a newly industrialized country by the year 2020. If this goal is to be achieved, then it is desirable that adequate and reliable energy supply to meet the resultant increasing energy demands by the various consumption sectors must be guaranteed. Kenya’s industrial development planning must therefore incorporate a vibrant and matching development in power supply.

Hydropower resource is currently the most established in the country and accounts for over 70% of total electricity supply. The *Sessional Paper No.2* of 1996 on ” Industrial Transformation by the year 2020” emphasizes the development of hydropower and other renewable energy sources as an important strategy to achieve the desired power supply.

Hydropower generation depends on availability of water, which in turn depends on the prevailing climatic conditions. Fluctuations in climatic parameters such as wind flow, rainfall and temperature affects, evapotranspiration rates that in turn affect water in reservoirs, the determinants of channel flow and power generation rates. This makes hydropower highly dependent and sensitive to climatic fluctuations especially the extremes such as droughts and floods.

Droughts are known to be accompanied with low water levels in the major dams while floods bring a lot of silt into the dams that can sometimes lead to destruction and damage to the turbines. A good example of the negative impacts of climate extremes was displayed by the 1999-2000 drought in which the low water levels in the dams led to severe countrywide power rationing resulting into large losses to the economy.

It should be noted that the impacts of such climate fluctuations on the hydropower resource can directly or indirectly affect the welfare of the communities and tend to enhance poverty. So pervasive are the implications of climate fluctuations that the energy sector urgently requires to develop some coping strategies to counter the adverse impacts of climate extremes. In this regard, climate forecasts:

(i) Are valuable to the sector to the extent that they may provide knowledge that can be used to cope with climate variations
(ii) May improve the outcomes of the sector
(iii) Are useful if they meet the sector's needs in terms of such attributes as timings, lead time, spatial and temporal resolution as well as accuracy

DMCN and KMD issue regular climate outlooks especially at the beginning of every major rainfall season. While the outlooks have inherently proved valuable, user uptakes of the forecast information has been limited and their full potential value is yet to be realized. *Oludhe et-al, 2001* in their investigation on the use of climate information use by various users such as KenGen indicated that:

(i) The user was unable to translate the rainfall forecasts into river flows
(ii) The forecasts were not user friendly on account of the complicated language being used
(iii)The forecasts never reached the institution in time so as to assist in long-term planning.

It is in view of the shortcomings mentioned above, this study attempts to sensitize and build the capacity of hydropower generation personnel within the energy sector and in particular the staff of KenGen on the use of the available climate prediction products in addressing the potential impacts of climate fluctuations on hydropower resource.

3.0 OBJECTIVES OF THE STUDY

An overall objective of this study is to sensitize and build the capacity of hydropower experts in utilizing climate information and prediction products in the planning and management of the hydropower resource as well as adapt and/or mitigate against any negative impacts of climate fluctuations on the resource.

The specific objectives include:

(i) Assessment of the level of usage of climate information and prediction products in power generation decision making in the context of timings, understandability, accuracy and perceived relevance.
(ii) Development of a methodology for translating the DMCN/KMD forecasts into actual amounts that translates to river flows in the respective hydropower catchment areas
(iii) Investigating the teleconnections between river flows and the global ocean Sea Surface Temperatures (SSTs), QBO, ENSO as well as Zonal Gradients (ZG) so as to develop predictive models for river flows and hence power generation
(iv) Documentation of the climate information repackaging needs for the hydropower sector

4.0 METHODOLOGY

The method of analysis used in this study included the following:

(i) Detailed examination and evaluation of data to be gathered via a questionnaire with regard to the level of usage of climate information and repackaging needs for effective utilization
(ii) Acquire rainfall, streamflow, dam levels and power generation data from the major dams in Kenya.
(iii) Statistical analysis of all data collected (River flows, rainfall, discharge and power output as well as QBO, ENSO, SSTs and ZG so as to come up with the prediction models
(iv) Build capacity of the staff in the power sector in the use of integrating climate information and prediction products in the planning and management of the hydropower resources.

5.0 RESULTS AND ACCOMPLISHMENTS

The study has gathered all the relevant data and information needed for the completion of this study. A structured questionnaire was developed for use in data gathering (see Annex A). The relevant data gathered in this study included:

- Rainfall data in the Tana River Catchment area
- River inflows into Masinga and Kamburu Dams.
- Total power demand and trend (month by month) over the last 10 years.
- Net power (month by month) shortfall over the last 10 years.
- Information on the usage of climate information and prediction products by KenGen

5.1 Rainfall, Inflow, Dam Level and Power Generation Data

Rainfall data for the Upper Tana River Basin were obtained from the Kenya Meteorological Department (KMD) and KenGen Headquarters in Stima Plaza. The rainfall data from KMD comprised of monthly rainfall values from eight stations from 1961 - 2002. The stations included Nyeri Ministry of Works (MoW), Embu Meteorological Station, Meru, Karatina, Naromoru, Othaya Agricultural Office, Kiandongoro Hydromet and Kerugoya Water Dev. Station.

The rainfall data from KenGen were obtained from a total of ten stations for the period ranging between 1967 to 2003. The stations included rainfall data from Sagana, Mesco, Wanjii, Tana, Ndula, Masinga, Kamburu, Gitaru, Kindaruma and Kiambere Power stations.

The inflow data used were those from Masinga and Kamburu Dams over the period between June 1982 - January 2003 while the dam levels for Masinga, Kamburu, Gitaru, Kindaruma and Kiambere were for the period between June 1981 - January 2003. The electrical power generation data between January 1990 and January 2003 for Masinga and Kamburu, were also obtained from KenGen Headquarters.

Table 1 below shows the duration of the rainfall data obtained from KenGen Company while ***Figure 1***depicts the position of the existing and proposed generation stations that include among Sagana, Mesco, Wanjii, Tana, Ndula, Masinga, Kamburu, Gitaru, Kindaruma and Kiambere Power stations.

Table 1: KenGen Rainfall data used in the study

Power Station Name	Period of the rainfall data
Sagana	1967 – 2003
Tana	1967 – 2003
Wanjii	1967 – 2003
Kindaruma	1968 – 2003
Kamburu	1974 – 2003
Gitaru	1978 – 2003
Masinga	1982 – 2003
Ndula	1982 – 2003
Kiambere	1982 – 2003
Mesco	1984 – 2003

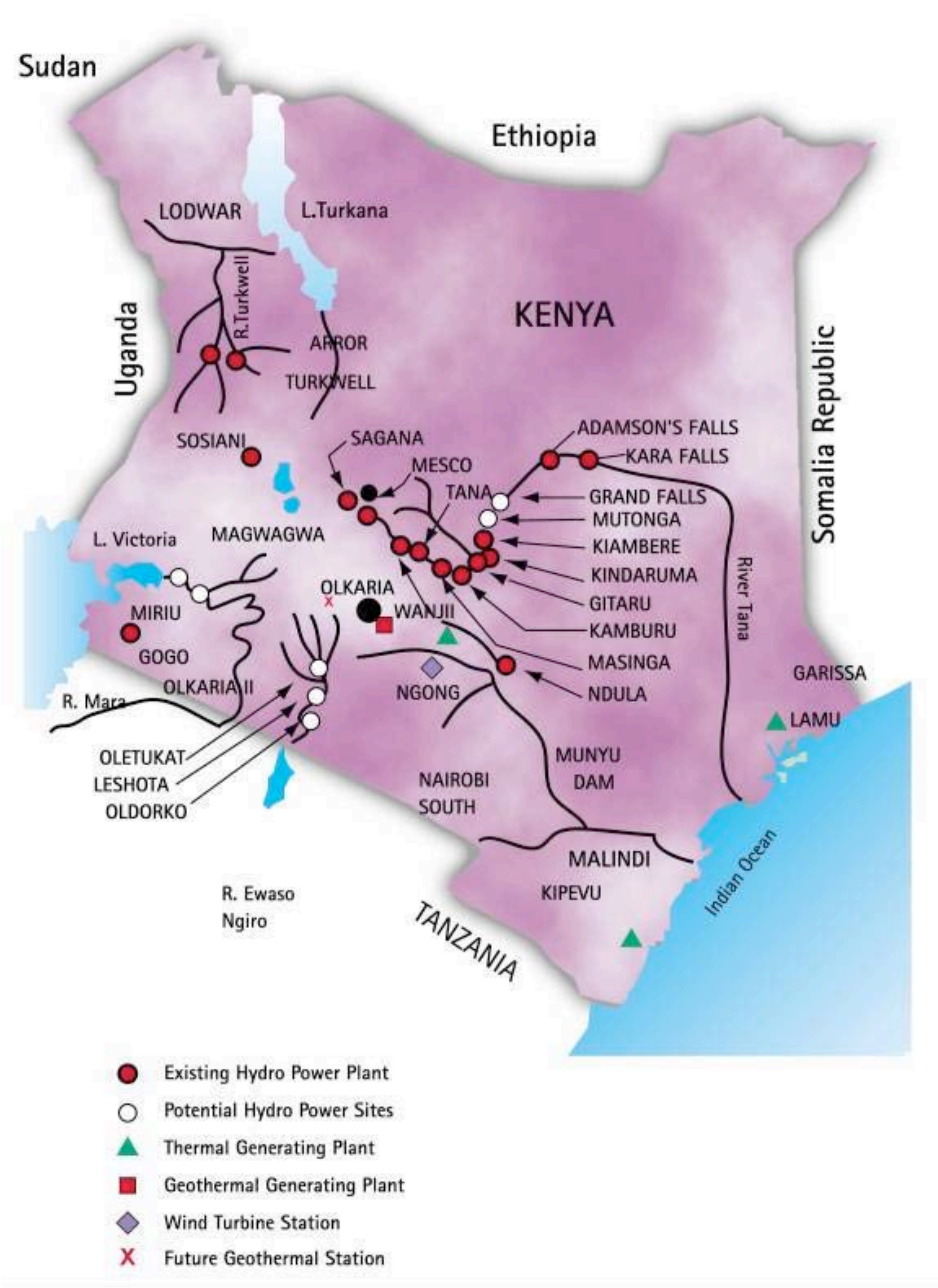

Figure 1: *Distribution of Existing and Planned Power stations within the area*

5.2 Electrical Power Transmission And Distribution

Kenya's energy sector comprises petroleum, electricity and the renewable energy sub-sectors. The overall large hydropower potential in Kenya is estimated at about 2263 MW while the Small, Mini and Pico hydros are estimated at 3000 MW. Out of this potential 707 MW has been developed and connected to the national grid. Another capacity of about 1 MW of mini and micro hydro has been developed for own use mainly by institutions and commercial agricultural enterprises. Another 60 MW is currently under development on the Sondu Miriu River and is expected to come on stream by mid 2004.

Since socio-economic development depends on adequate power supply, the government has formulated a power development strategy to develop a reliable and self-sufficing system by exploiting the country's hydropower potential and enhancing the transmission and distribution system.

Kenya derives its electric power from hydro, thermal and geothermal sources. 82 percent of Kenya's power is supplied by hydropower. Other major energy sources include geothermal (8%), thermal (8.7%) and wind (0.01 %). The country's total electricity consumption in 1997 was 3824GWh, of which approximately 3050GWh was supplied by hydropower. Most of the consumption is by commercial and industrial establishments, institutions and households. Electricity is supplied at 240 volts, 50 cycles single-phase and at 415 volts, 50 cycles three-phase. Other commonly used sources of power include solar power, biogas and wind energy.

Power generation diversification is being reviewed in an attempt to reduce the adverse effects of drought on supply. 383 out of the 527 megawatts that will be connected to the national grid by the year 2003 will be generated from non-hydro power sources.

There are 14 large dams in operation within Kenya. The total water storage volume of all reservoirs is approximately 3 km^3. No major dams are under construction, but development of three is planned, including Sondu Miriu (60 MW), Ewaso Ngiro (180 MW), expected to be commissioned in 2008-2009, and Low Grand Falls/Mutonga (180 MW) commission slated for 2008-2012.

Electricity is the third largest form of energy and the second ranked commercial energy in Kenya after biomass and petroleum. The installed electric power generation stood at about 1172 MW by September 2001 and corresponded to an effective generation capacity of about 1066 MW. This installed capacity comprises hydro plants, 707 MW; geothermal, 57 MW and petroleum fired, 475 MW.

Geothermal resources in Kenya are located within the Rift Valley and their potential for power generation is estimated at over 2000 MW out of which 57 MW is already developed and connected to the grid. Another 100 MW is currently under development, with the first 64 MW scheduled for commissioning by financial year 2002/3. The remaining 36 MW was scheduled for commissioning in third quarter of 2003.

The electric power sub-sector has a total installed generation capacity of 1,172 MW. KPLC owns and operates Kenya's national transmission and distribution grid. The Company is responsible for ensuring that there is adequate line capacity to maintain supply and quality of electricity across the country. The total interconnected network of transmission and distribution lines is about 20,000 km.

Table 2 below shows the annual gross generation by source for the period 1997/8 to 2001/2 while ***Table 3*** presents the Gross generation of power in Kenya from Interconnected and Isolated Systems over the last 10 years.

Table 2: *Gross Generation (GWh) by Source (1997/8-2001/2)*

Sources	**Year**				
	1997/1998	**1998/1999**	**1999/2000**	**2000/2001**	**2001/2002**
Hydro	3,405	3,414	2,590	1,523	2,588
Thermal	713	799	1,458	2,099	1,512
Geothermal	366	390	383	429	459
Wind	1	0	0	0	0
TOTAL	**4,485**	**4,603**	**4,431**	**4,051**	**4,559**

5.3 Receipt of the KMD/DMCN Forecasts by KENGEN

KenGen is in the mailing list of KMD and any product from KMD is forwarded to KenGen's Chief Generation Manager who then passes over the same information to all the relevant departments within the company. KenGen is well represented in all the DMCN Climate Outlook Fora Mr. Daniel Kimani who is the Senior Hydrologist with the company.

Table 3: Gross Generation for Interconnected and Isolated Systems for the Last 10 Years (Source: KenGen Annual Report, 2002)

POWER STATION LOCATIONS	**Capacity (MW) AS AT 30.6.2002**		**ENERGY (GWhr)**									
HYDRO	Installed	Effective*	1991/92	1992/93	1993/94	1994/95	1995/96	1996/97	1997/98	1998/99	1999/00	2000/01
Tana	14.4	12.4	72	75	64	78	97	84	76	82	63	71
Wanji	7.4	7.4			30	27	51	48	51	35	46	47
Kamburu	91.5	84.0	402	417	421	485	491	446	480	410	247	181
Gitaru	145.0	145.0	811	844	856	704	701	926	818	789	734	364
Kindaruma	40.0	40.0	206	213	217	213	239	230	198	240	157	81
Small Hydros	6.2	5.4			17	22	29	24	26	21	19	20
UEB (Imports)	30.0	0.0	240	273	264	187	149	144	146	140	155	198
Masinga	40.0	40.0	185	177	180	200	225	215	204	223	142	28
Kiambere	144.0	144.0	872	887	892	996	1031	1028	1023	1037	813	293
Turkwel	106.0	106.0	166	275	371	379	299	353	384	436	218	240
TOTAL HYDRO INCLUDING IMPORTS	624.5	584.2	3016	3246	3312	3290	3312	3497	3404	3414	2590	1,523
THERMAL												
Kipevu Steam	45.5	36.0	75	59	140	218	224	200	201	141	199	126
Kipevu I (75MW Diesel)	75.0	70.0	0	0	0	0	0	0	0	0	393	449
GEOTHERMAL *Olkaria I*	45.0	45.0	272	272	261	290	390	393	366	390	381	340
Olkaria III (IPP)	8.0	8.0									2	
GAS TURBINE												
Fiat-Nairobi South	13.5	10.0	2.9	2.1	2	16	59	6	0	15	30	35
Kipevu GT 1 & 2	60.0	60.0	0	0	0	31	112	168	139	191	384	274
DIESEL												
Ruiru	0.0	0.0	3.37	0.26	0	2	2	3	0	0	0	0
Independent Power Producers (IPPs)	87.5	87.5	-	-	-	-	-	7	383	463	463	
WIND TURBINE-*Ngong*	0.4	0.4			1	1	1	1	1	0	0	0
Interconnected System	876.4	823.1	3370	3580	3715	3848	4100	4274	4495	4615	4441	
ISOLATED DIESELS												
KPLC Diesel Stations	3.8	3.5	6.7	7.0	9	10	11	11	11	11	10	10
REF Diesel Stations	5.4	4.6	9.5	11.2	8	7	8	11	10	11	10	10
TOTAL ISOLATED DIESELS (Lamu and Garissa)	9.2	8.1	16	20	17	17	19	22	21	22	19	
GROSS GENERATION	**885.6**	**831.1**	**3386**	**3599**	**3732**	**3866**	**4119**	**4296**	**4516**	**4637**	**4461**	

5.4 Variation of electrical power outputs with dam levels for Masinga and Kamburu

The poor rains in of March – May 2000 as predicted by KMD/DMCN resulted in low water levels in Masinga and Kamburu Dams. By April 2000, the water flow to Masinga Dam was only 15% of the long-term average of the river flow. In view of the low water levels in Masinga Dam, KPLC in consultation with all stakeholders (Government, Industry and Domestic consumers) had to resort to enhanced power rationing of 12 hours for both domestic and industrial consumers until the rains improve. The consequence of this was devastating to Kenya's economy as shall be presented in the later sections.

During the 1997/98 El-Niño floods, the Masinga dam was full to capacity (and so were the other dams down the cascade). A major rainfall deficit occurred in the 7-forks dams starting from the short rains (OND) of 1998 all through to the short rains of OND 2000. The low water levels in the dams consequently led to under performance of the turbines and below average electricity generation that caused a power deficit of nearly 197 MW.

Figure 2a below give the monthly variation of Masinga dam levels between January 1990 and August 2003. ***Figure 2b*** gives the anomalies for the dam over the same period. It can clearly see from these figures that the period June to December 2000 was generally characterised by low water levels in the dam and this resulted in reduced power outputs. ***Figure 2c*** gives the variation of SST anomalies over the Equatorial Pacific Ocean and it can be seen that the positive/negative anomalies correlates well with the water levels in the Dam.

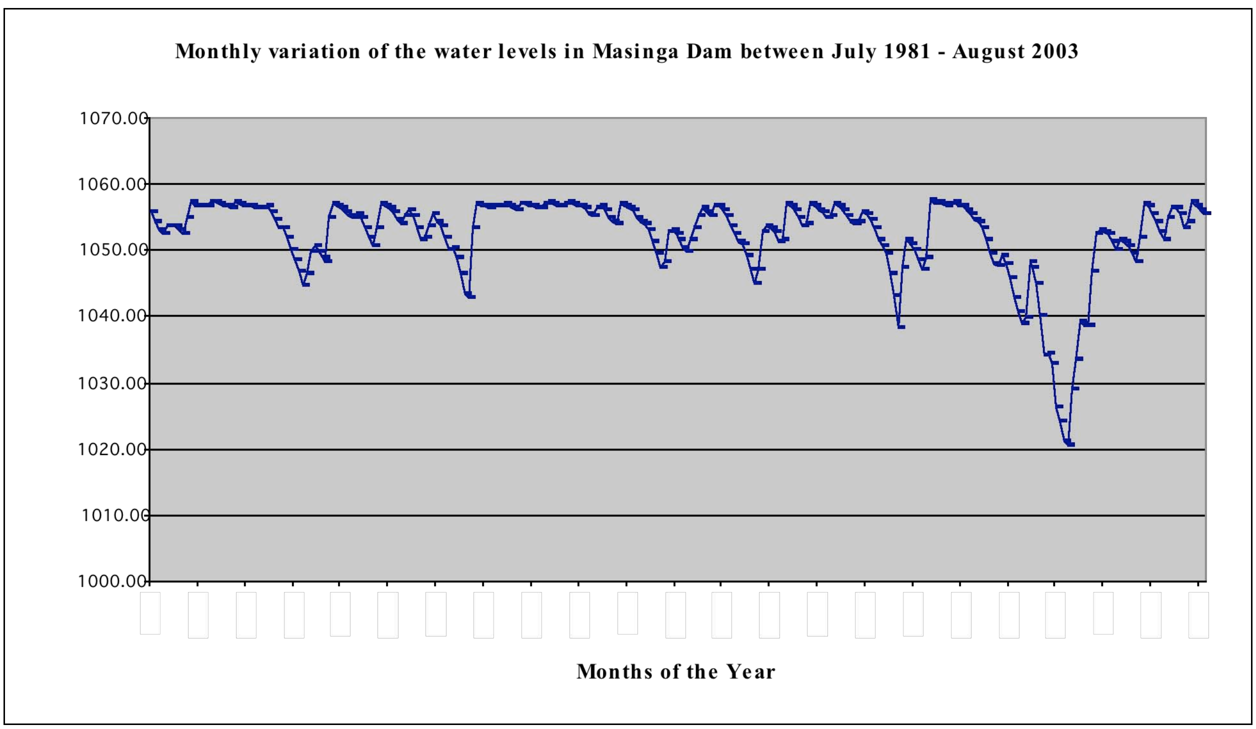

Figure 2a: *Monthly variation of the water levels in Masinga*

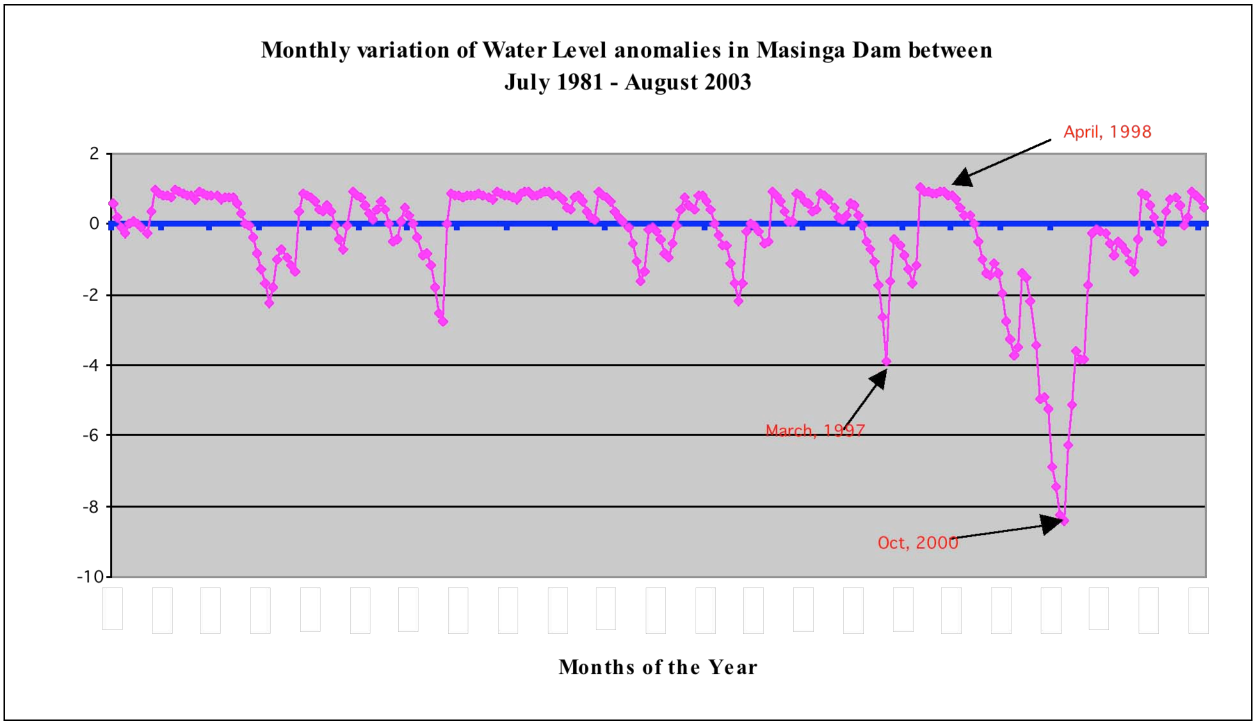

Figure 2b: *Monthly variation of the normalised water levels in Masinga Dam*

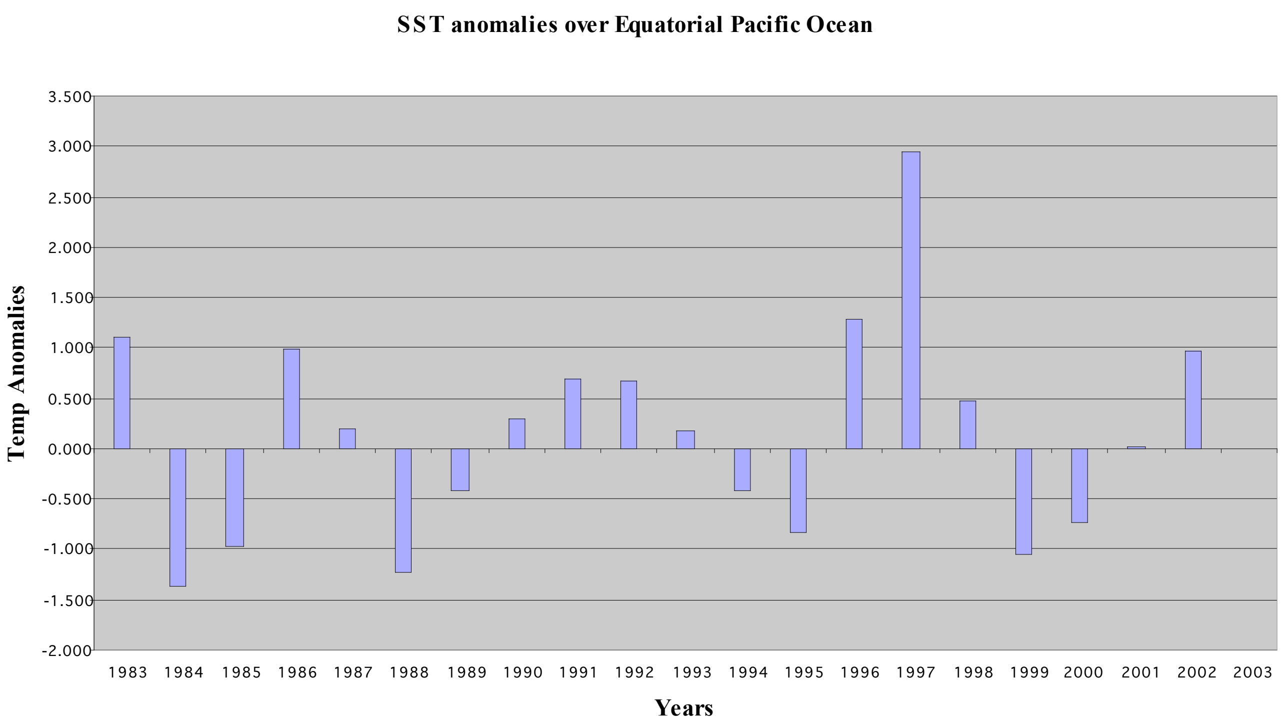

Figure 2c: *Monthly variation of the normalised water levels in Masinga Dam*

Figure 3 presents the variation of the electrical energy output and total energy output Masinga and Kamburu power stations within the 7-Forks dams. The variations are quite similar to those observed with the level of water in the dams (Figures 2a and 2b)

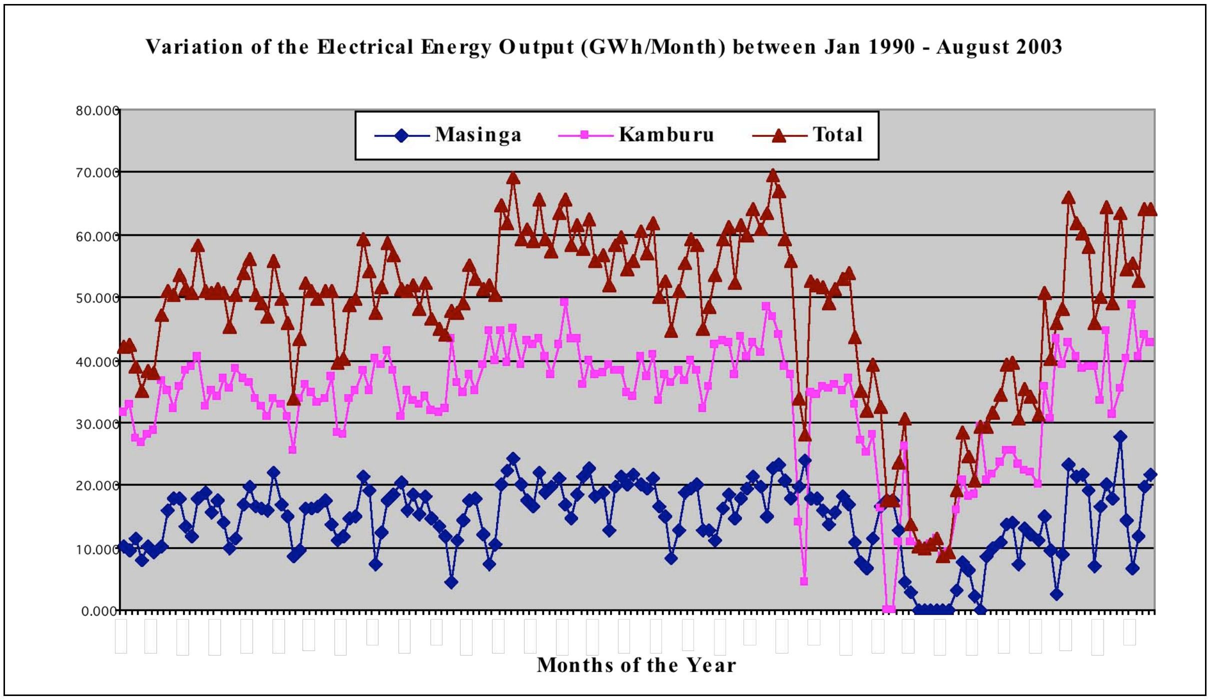

Figure 3: *Monthly variation of Electrical Power output in Masinga and Kamburu Dams*

Figure 4a: *Masinga Dam filled to capacity after the 1997/98 El-Nino Rains*

***Figure 4b: Reduced water levels in** Masinga Dam following the Dry spells in the country*

Figures 4a and ***4b*** above are pictures of the Masinga dam during periods of good and poor rainfall in the upper catchment of the Tana River Basin. Figure 4a is an example of what might be expected during the El-Nino related rains while Figure 4b is for La-Nina related droughts. Kenya have in the recent past experienced these two major extreme climate events that led to severe socio-economic impacts such loss of life and property, damage to infrastructure, mass migration of animals and society, disruption of power supply, water shortage, famine among many other socio-economic miseries.

The Inadequate rainfall during the prolonged 1999-2001 drought led to a serious shortage in the supply of electricity in Kenya and the consequence of this was the start of rationing power in Kenya. ***Figure 4c*** is a typical example of what might be expected in the event of drought and the devastation that drought causes to the Dams in the country.

Figure 4c: *Masinga Dam* ***at its lowest levels*** *following the La-Nina Drought of 1999/2001*

6.0 Rainfall and Inflow Prediction for the Tana River Basin

The systems that control the space-time patterns of rainfall over Kenya have been identified as the Inter-tropical Convergence Zone (ITCZ), Moonsonal Winds, African Sub-tropical Anticyclones, Tropical cyclones, Easterly/Westerly Waves Perturbations, Extratropical weather systems, Teleconnections with Quasi-Biennial Oscillation (QBO), Intraseasonal Waves, El-Niño/Southern Oscillation (ENSO), Global Sea Surface Temperatures (SSTs) and Thermally induced Mesoscale systems associated with complex topography and the large water bodies.

Research has shown that teleconnections exist between the seasonal rainfall over many areas of the world with Global SSTs, QBO and ENSO. Current prediction tools for rainfall over Kenya tend to use these parameters as input into statistical regression equations. The development of the multiple linear regression equation requires that a relationship (correlation) be established between rainfall/discharge over the study location and SSTs over the different global oceans. This is achieved through use of computer software, known as CLIMLAB 2000, developed by the International Research Institute (IRI) in the USA. Once the highly correlated SST regions are found, the final stage will be to develop the regression model, verify it and use it as a prediction tool for the variable in question. This procedure is briefly discussed in the section below.

6.1 Fitting a Simple and Multiple Linear Regression Models

A simple linear regression model (SLRM) describes the linear relationship between two variables X (independent or predictor) and Y (dependent or predictand). In reality, forecasting problems require more than one predictor as is in the case of multivariate regression analysis. In fitting the simple linear regression model equation, you hypothesize the form of the model to be: $Y = a_0 + a_1 X + \varepsilon$ which contains the deterministic part, $a_0 + a_1 X$ and the error term, ε. a_0 and a_1 are the regression constants to be determined from the sample data. The fitting of the Multiple Linear Regression Model (MLRM) is similar to that of SLRM that is usually done through the least squares method. In a multiple regression model, a single predictand, Y, has more than one predictor variable, X. Let k denote the number of predictor variables, then the prediction equation is: $Y = b_0 + \sum_{i=1}^{n} b_i x_i + \varepsilon_i$, where b_0 *and* b_i are the intercept and regression coefficients for the predictors, x_i. The variance of the error term, in this case is $S^2 = \frac{SSE}{n-(k+1)}$, while a test of the adequacy of the model is done by computing R^2, (the multiple coefficient of determination), given by $R^2 = 1 - \frac{SSE}{\sum_{i=1}^{n}(Y-\overline{Y})^2}$. For $R^2 = 0$, it implies Lack of fit, while $R^2 = 1$ implies perfect fit.

Stepwise Regression technique is normally used during the fitting of multiple regression models so as to pick the best individual predictors, $x_1, x_2, \text{----} x_n$ into the multiple regression model equation. At each moment, a single predictand is added into the equation based on the amount of variance that predictand can explain into the model. A typical window for extracting the SSTs using CLIMLAB 2000 is shown below.

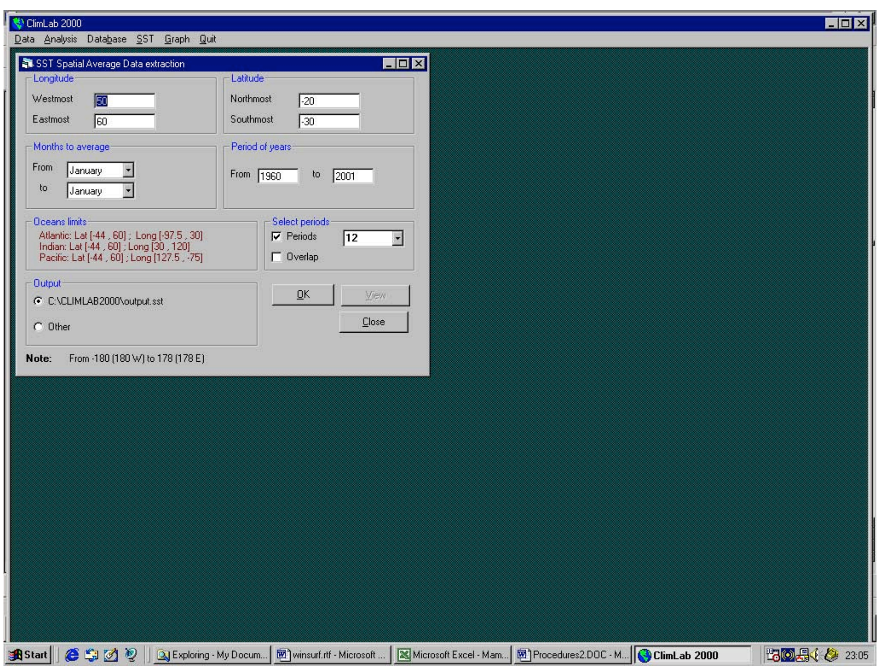

Figure 5: *Typical Window for extracting the SSTs using CLIMLAB 2000 Software*

The results obtained from the analysis of the global oceans are presented in ***Table 4*** below. This table summarizes the global ocean areas that were selected in the regression model development through stepwise regression analysis.

Table 4: A summary of the global ocean areas selected in the regression model development

Anomaly Investigated	OCEAN AREAS SELECTED								
	Pacific Ocean			Atlantic Ocean			Indian Ocean		
	Name	Lat.	Long.	Name	Lat.	Long.	Name	Lat.	Long.
MAM Rainfall	SIN	35°S-40°S	38°E-30E	-	-	-	EIN1	5°N - 10°N	110°E - 115E
OND Rainfall	NP1 EQP	25°N-35°N 0°N-8°N	122°W-142°W 165°W-179°W	SAT1 SAT2	28°S-35°S 32°S-35°S	10°E-12°E 14°W-18°W	SIN EQIN EIN1 EIN2	35°S-44°S 7°S-15°S 3°S-8°S 7°S-3°N	27°E-38°E 72°E-82°E 100°E-110°E 127°E-135°E
MAM Inflow for Masinga	SP2	12°S-22°S	150°W-175°W	-	-	-	SIN EQIN2 MZC	33°S-40°S 3°S-5°N 11°S-15°S	20°E-40°E 50°E-70°E 40°E-50°E
MAM Inflow for Thiba	SP2	12°S-22°S	150°W-175°W	-	-	-	SIN EQIN2 MZC	33°S-40°S 3°S-5°N 11°S-15°S	20°E-40°E 50°E-70°E 40°E-50°E
OND Inflow into Masinga Dam	NP4	30°N-35°N	128°W-135°W	-	-	-	EQIN EIN	4°S-9°S 3°S-8°S	45°E-55°E 98°E-108E
OND Inflow for Thiba	SP	20°S-28°S	70°W-105°W	NAT	22°N-28°N	12°W-20°W	EQIN EIN	4°S-9°S 3°S-8°S	45°E-55°E 98°E-108E

6.2 Model statistics developed from the regression analysis

Table 5 below presents the results of the regression analysis and the models developed for both MAM/OND rainfall and inflow data used in this study. The table shows that R^2 for OND produced larger values than their corresponding MAM values for each of the rainfall and inflow cases.

Table 5: Regression model Statistics

PREDICTAND	MULTIPLE REGRESSION MODEL EQUATIONS	R	R^2	F-Ratio	P-Value
MAM-Rainfall Anomaly	0.765* SIN1JAN-0.566*SIN1FEB + 0.504*EIN1FEB	0.749	0.55	10.80	0.000
OND-Rainfall Anomaly	-0.135 +0.219*SIN1JUN - 0.575*SAT1JUL + 0.295*SAT2JUL + 0.577*NP1JUL +0.317*EQPJUL - 0.408*EQINJUL - 0.452*EIN1JUL + 0.579*EIN2JUL - 0.818*JUNSOI	0.967	0.94	13.29	0.000
MAM Inflow into Masinga Dam	-0.503*SP2Feb -0.456*SINFeb + 0.777*EQIN2Feb -0.277*MZCFeb	0.951	0.90	32.96	0.000
MAM Inflow for Thiba	-0.342*SP2FEB - 0.579*SINFEB + 0.777*EQIN2FEB - 0.360*MZCFEB	0.928	0.86	21.80	0.000
OND Inflow into Masinga Dam	0.020 + 0.479*NP4JUL + 0.490*EQINJUL - 0.649*EINJUL + 0.331*JULSOI	0.932	0.87	23.98	0.000
OND Inflow into Kamburu Dam	0.341*SPJUL + 0.532*NATJUN - 0.398*EQIN1JUN - 0.570*EINJUL - 0.207*MAYQBO	0.965	0.93	33.61	0.000

The predictions of inflow anomalies for MAM 2001 and 2003 into Masinga and Kamburu dams are as given in ***Figures 6a – 6f*** respectively.

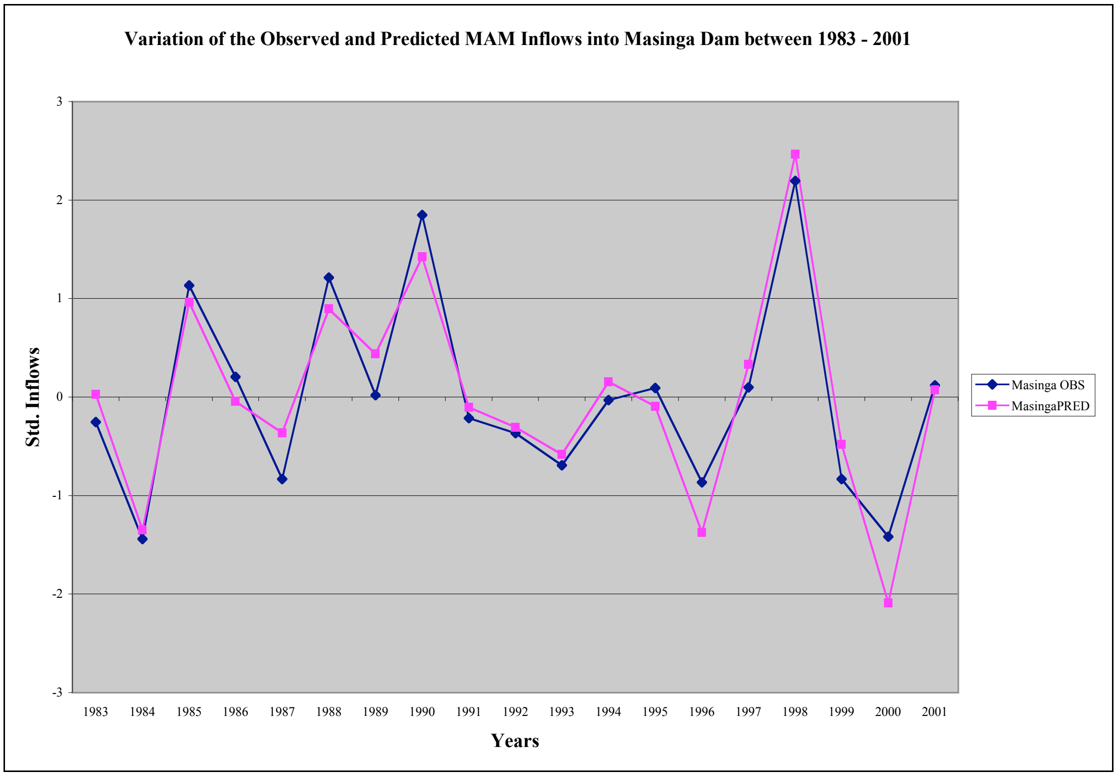

Figure 6a: *Comparison between Observed and Predicted MAM Inflow anomaly into Masinga Dam between 1983 - 2001.*

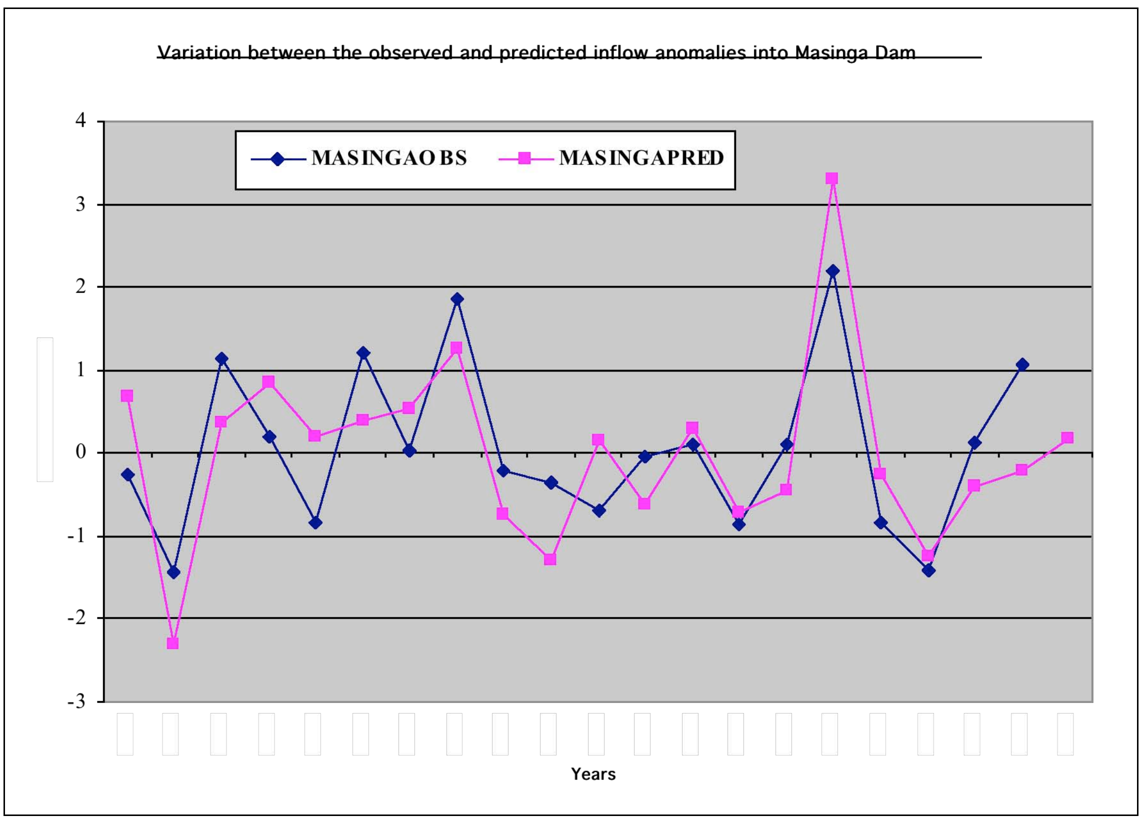

Figure 6b: *Comparison between Observed and Predicted MAM Inflow anomaly into Masinga Dam between 1983 - 2003.*

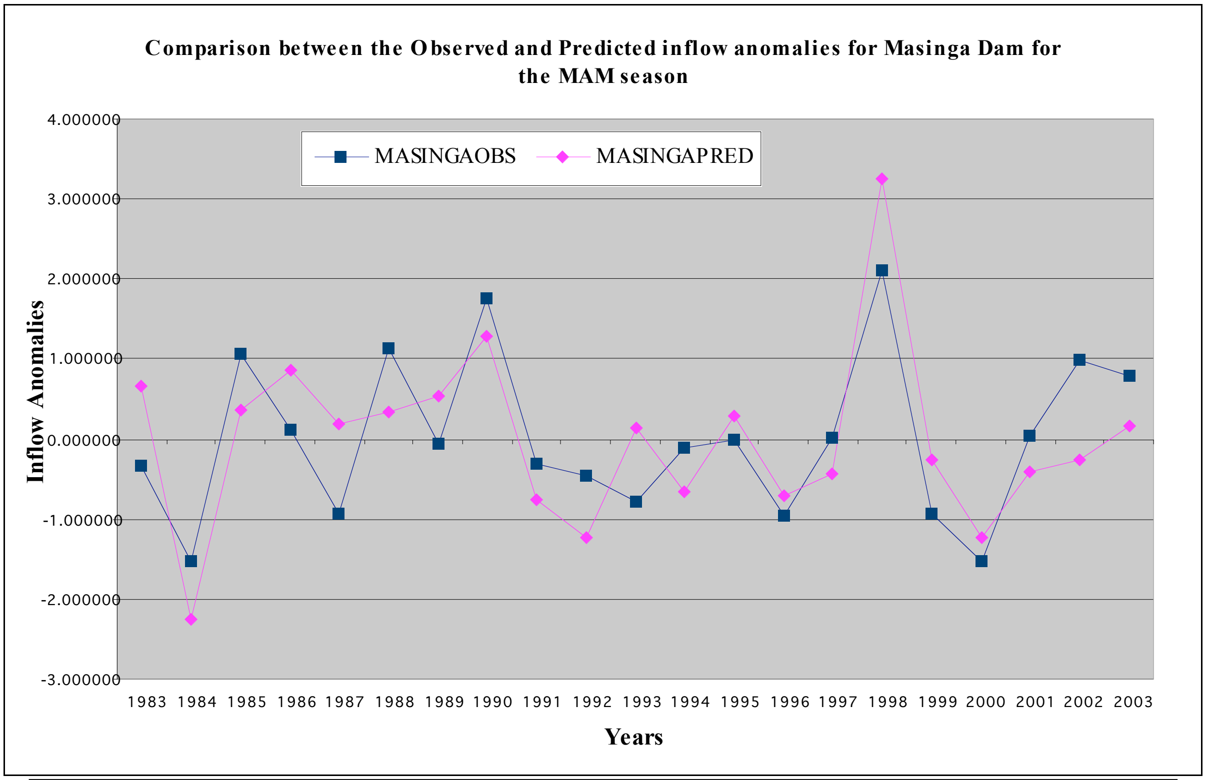

Figure 6c: *Comparison between Observed and Predicted MAM Inflow anomaly into Masinga Dam between 1983 - 2003.*

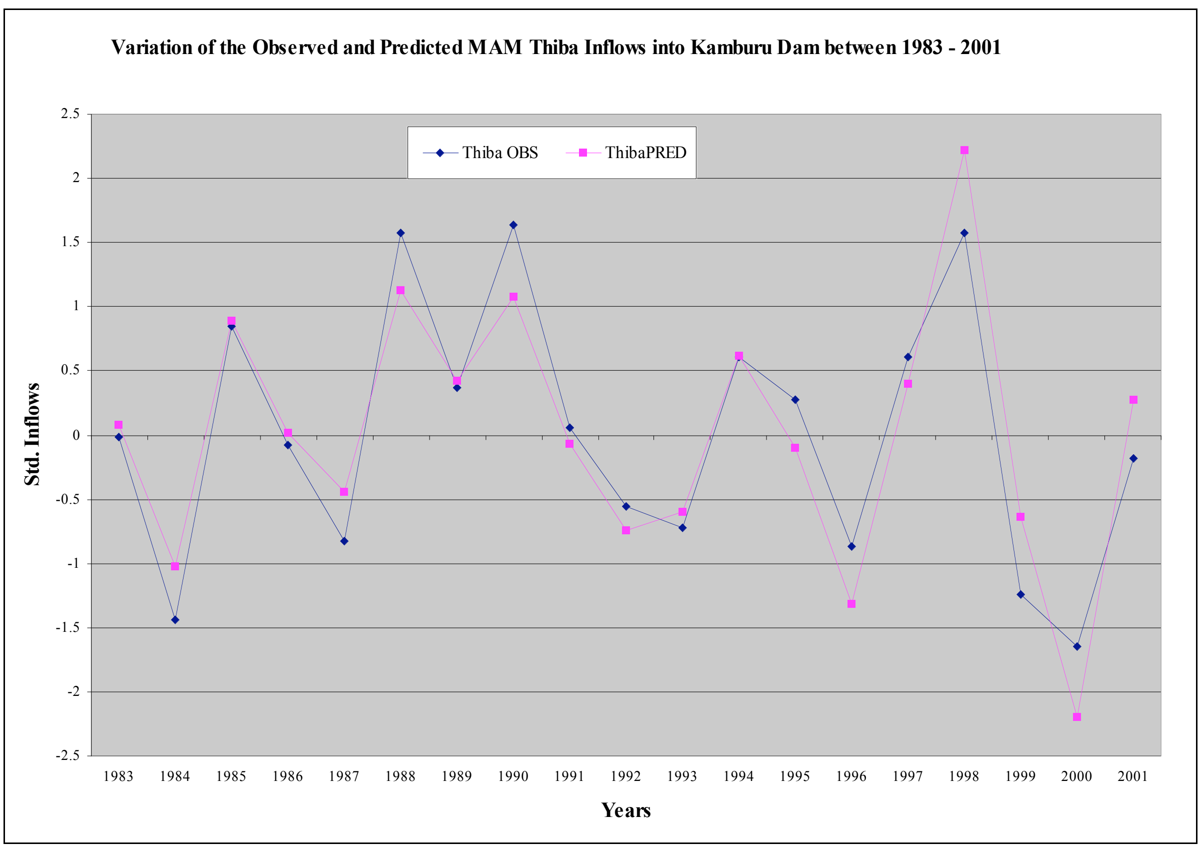

Figure 6d: *Comparison between Observed and Predicted MAM Thiba Inflow anomaly into Kamburu Dam between 1983 - 2001.*

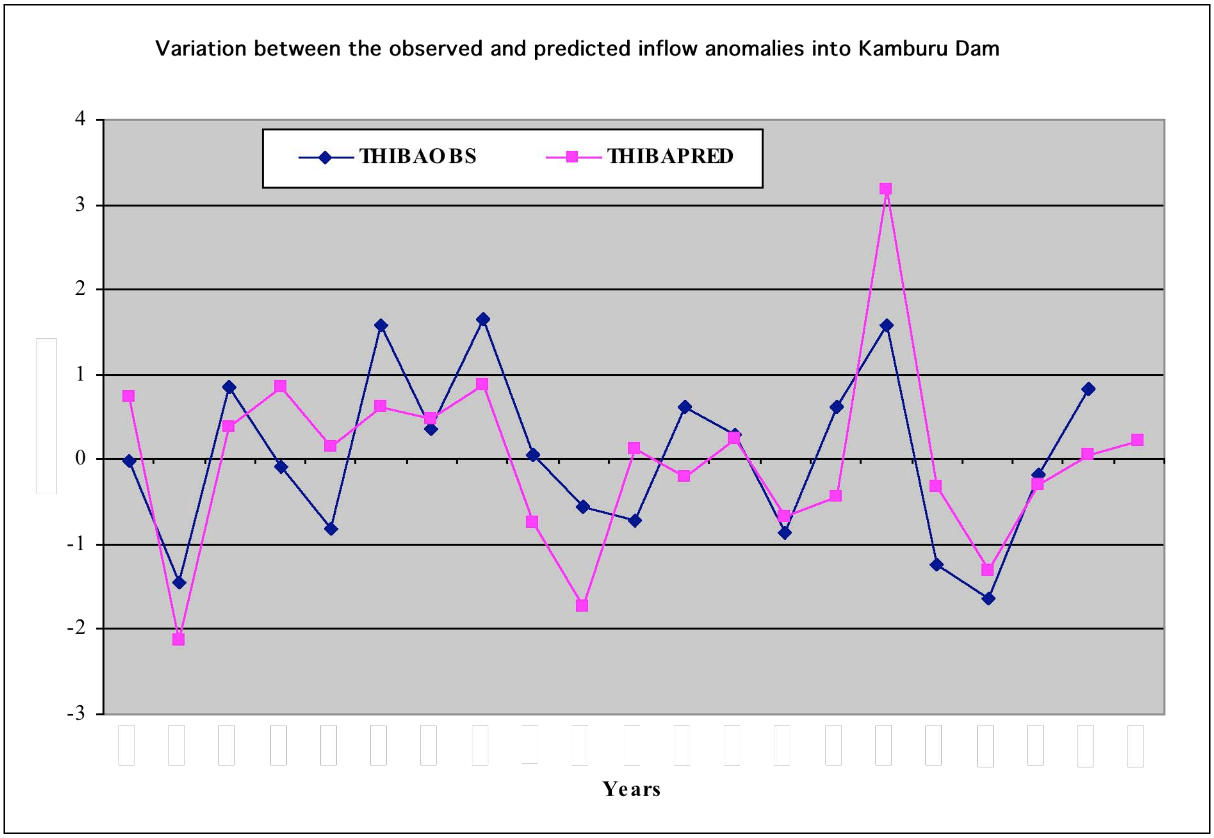

__Figure 6e:__ Comparison between Observed and Predicted MAM Thiba Inflow anomaly into Kamburu Dam between 1983 - 2003.

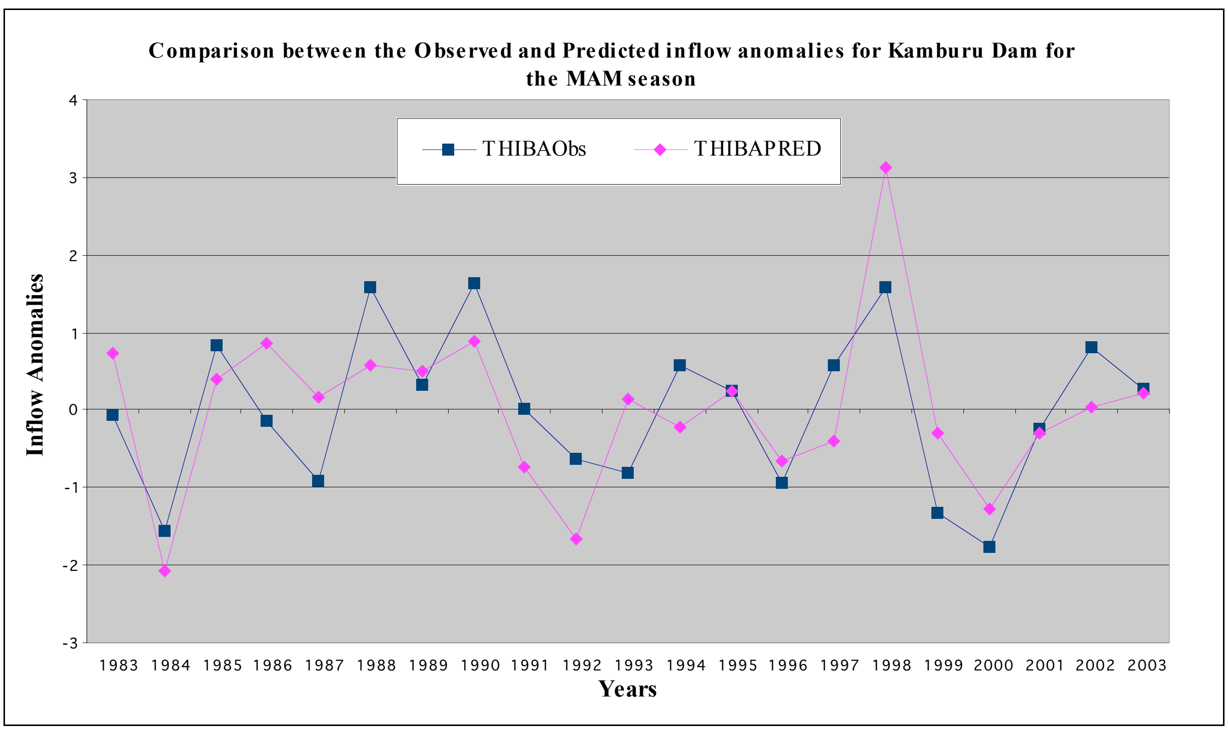

__Figure 6f:__ Comparison between Observed and Predicted MAM Thiba Inflow anomaly into Kamburu Dam between 1983 - 2003.

It can be seen from the above figures that the predicted and the observed inflow anomalies for both the Masinga and Kamburu Dams for the MAM 2003 season are in good agreement with each other (See ***figures 6c*** and ***6f*** above). These anomalies were ranked and equated to the actual observed inflows for each dam as indicated below. This analysis was done as an attempt to convert the tercile anomalies into actual inflow magnitudes. The ranked anomalies and actual amounts for the inflows into Masinga and Kamburu dams are as given in ***Table 6*** below.

Table 6: Determining the Observed inflows from the predicted ranked anomalies

Year	Masinga actual MAM inflow Cumecs	Masinga Ranked Anomalies	Year	Thiba actual MAM inflow Cumecs	Thiba Ranked Anomalies
1984	52.6	-1.439	2000	14.3	-1.647
2000	57.1	-1.416	1984	25.2	-1.442
1996	166.4	-0.865	1999	35.9	-1.241
1987	173.2	-0.831	1996	55.9	-0.865
1999	173.3	-0.830	1987	58.2	-0.822
1993	200.7	-0.693	1993	63.5	-0.723
1992	265.6	-0.365	1992	72.3	-0.557
1983	288.2	-0.251	2001	92.1	-0.185
1991	296.0	-0.212	1986	97.7	-0.080
1994	332.3	-0.029	1983	101.2	-0.015
1989	342.1	0.020	1991	105.1	0.059
1995	356.4	0.092	**2003**	**113.5**	**0.216**
1997	357.9	0.100	1995	116.9	0.280
2001	362.0	0.121	1989	121.5	0.367
2003	**369.8**	**0.160**	1994	134.5	0.611
1986	378.9	0.206	1997	134.5	0.611
2002	548.9	1.063	2002	146.4	0.834
1985	563.2	1.134	1985	147.3	0.851
1988	579.2	1.215	1988	186.1	1.580
1990	705.0	1.849	1998	186.1	1.580
1998	773.6	2.195	1990	189.3	1.640

The table above clearly indicates that the predicted inflows into Masinga Dam fall in the above normal category with a magnitude equivalent to 369.8 cumecs, i.e.

Masinga Predicted (amounts) **369.8** = Masinga mean inflow (**338.1**) + Std.dev (**102.0**)* Predicted Anomaly (**0.160)** ± (44.5)

The Thiba inflow predictions are in the normal category as indicated in the table above with a magnitude equal to 113.5 cumecs, i.e.

Thiba MAM Predicted (amounts) **113.5** = Thiba mean inflows (**198.4**) + Std.dev (**53.2**)* Predicted Anomaly **0.216)** ± (23.0)

6.3 Predictions for the Month by Month inflows into Masinga Reservoir

Figures 7a – 7f below presents the results of the predictions of the month-by-month inflows into Masinga Dam during the months of March, April and May respectively.

The various statistics for the month of March as well as the model fit are as indicated below:

Multiple R: 0.927 squared multiple R: 0.860

Effect	Coefficient	STD Error	Std Coef	Tolerance	t	P(2 Tail)
CONSTANT	-0.047	0.091	0.000	.	-0.509	0.617
SP2FEB	**-0.550**	0.094	-0.560	0.951	-5.841	0.000
EQIN1FEB	**-0.596**	0.148	-0.602	0.390	-4.019	0.001
EIN4FEB	**1.054**	0.144	1.080	0.402	7.319	0.000

Analysis of Variance

Source	Sum-of-Squares	do	Mean-Square	F-ratio	P
Regression	16.341	3	5.447	32.774	0.000
Residual	2.659	16	0.166		

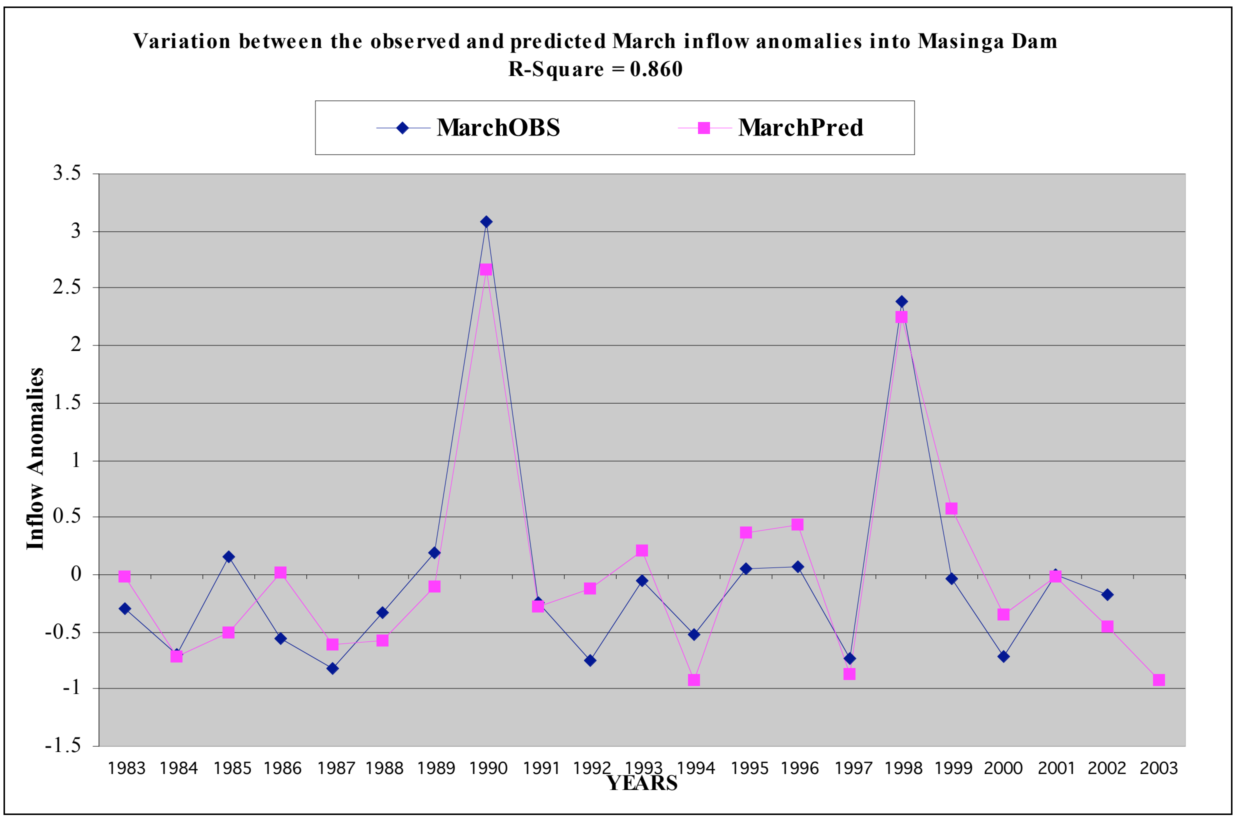

Figure 7a: *Comparison between Observed and Predicted March Inflow anomaly into Masinga Dam between 1983 - 2003.*

The various statistics for the month of April as well as the model fit are as indicated below:

Multiple R: 0.871 Squared multiple R: 0.759

Effect	Coefficient	STD Error	Std Coef	Tolerance	t	P(2 Tail)
CONSTANT	**0.067**	0.122	0.000	.	0.550	0.590
EP22	**0.581**	0.126	0.584	0.939	4.612	0.000
AT12	**-0.518**	0.125	-0.527	0.926	-4.135	0.001
MAB4M12	**0.201**	0.085	0.293	0.967	2.351	0.032

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Regression	**14.423**	**3**	**4.808**	**16.805**	**0.000**
Residual	**4.577**	**16**	**0.286**		

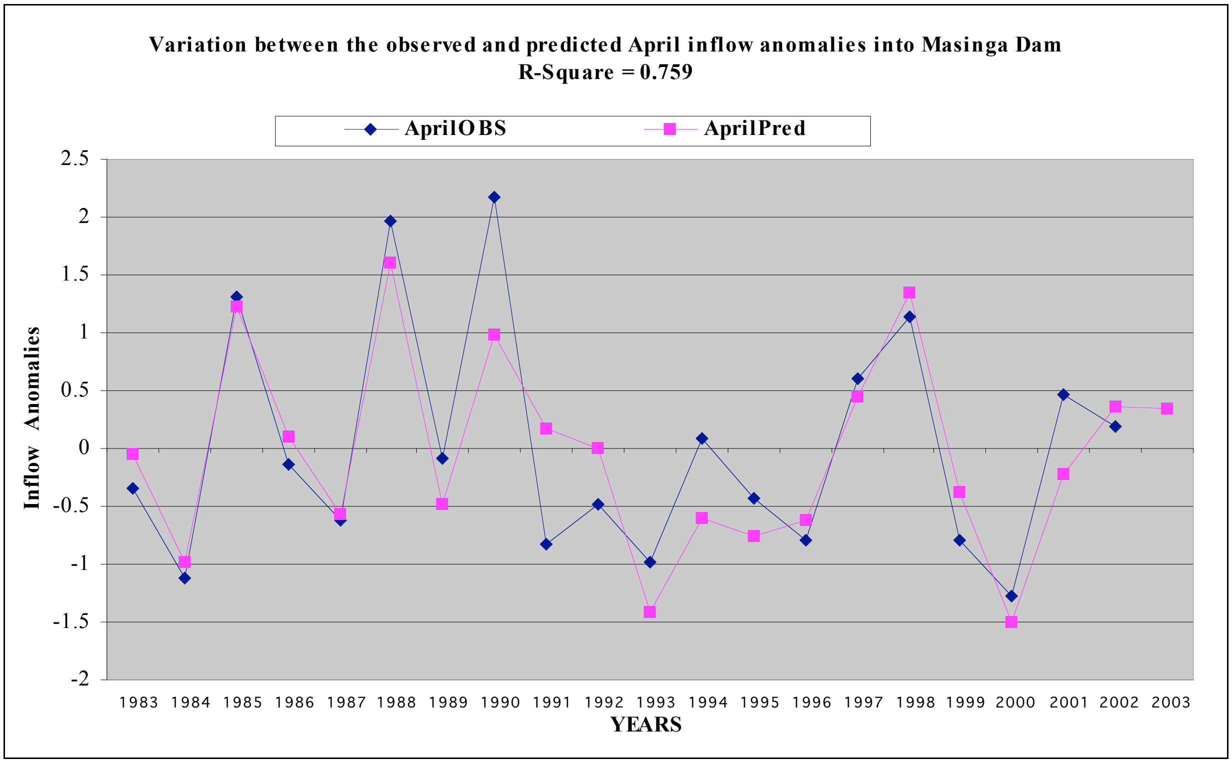

Figure 7b: *Comparison between Observed and Predicted April Inflow anomaly into Masinga Dam between 1983 - 2003.*

The various statistics for the month of May as well as the model fit are as indicated below:

Multiple R: 0.858   Squared multiple R: 0.737

Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)
CONSTANT	0.041	0.122	0.000	.	0.333	0.743
IN41	**0.700**	0.130	0.673	0.998	5.400	0.000
AT12	**-0.494**	0.122	-0.503	0.998	-4.034	0.001

Analysis of Variance

Source	**Sum-of-Squares**	**df**	**Mean-Square**	**F-ratio**	**P**
Regression	**13.995**	**2**	**6.997**	**23.765**	**0.000**
Residual	**5.005**	**17**	**0.294**		

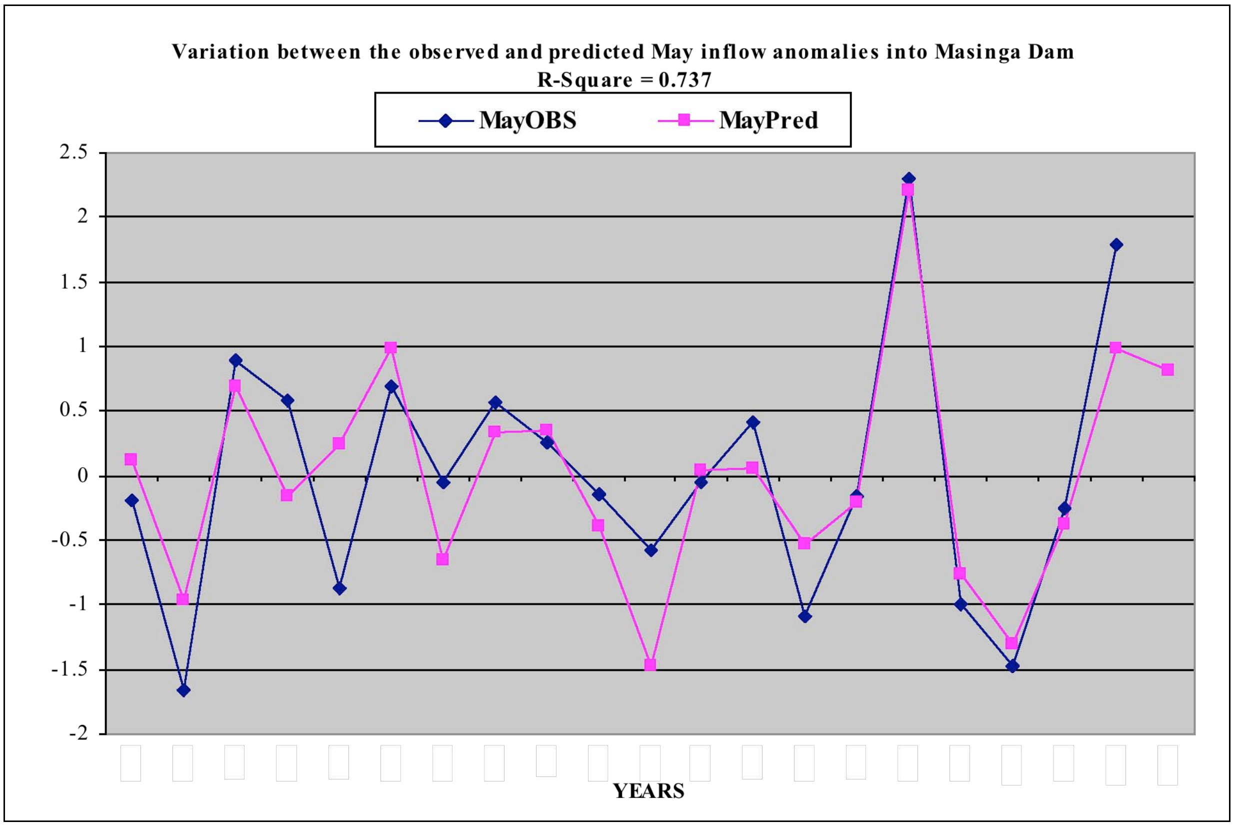

Figure 7c: *Comparison between Observed and Predicted May Inflow anomaly into Masinga Dam between 1983 - 2003.*

It can be seen from the above figures that apart from the predictions for March 2003 inflows that showed below normal, the April and May 2003 inflows indicated Near-Normal to Above Normal predictions. The ranked anomalies and actual amounts for the inflows into Masinga dam during the months of March, April and May are given in ***Table 7*** below.

Table 7: The Observed inflow anomalies from ranked forecasts for the months of March, April and May

Year	OBS inflow March	Pred inflow March	Year	OBS inflow April	Pred inflow April	Year	OBS inflow May	Pred inflow May
2003	**1.0**	**-0.9316**	2000	15.7	-1.2826	1984	13.2	-1.6544
1987	4.9	-0.8227	1984	30.1	-1.1154	2000	32.6	-1.4714
1992	7.4	-0.7503	1993	41.1	-0.9885	1996	72.6	-1.0939
1997	8.0	-0.7317	1991	54.5	-0.8327	1999	83.5	-0.9910
2000	8.8	-0.7101	1996	57.6	-0.7966	1987	96.0	-0.8738
1984	9.2	-0.6976	1999	57.7	-0.7957	1993	127.6	-0.5756
1986	13.9	-0.5636	1987	72.4	-0.6258	2001	161.9	-0.2514
1994	15.3	-0.5249	1992	84.6	-0.4843	1983	168.2	-0.1926
1988	21.8	-0.3401	1995	88.6	-0.4382	1997	171.6	-0.1605
1983	23.2	-0.2985	1983	96.9	-0.3420	1992	173.6	-0.1413
1991	24.9	-0.2491	1986	114.3	-0.1395	1989	182.8	-0.0544
2002	27.7	-0.1706	1989	119.2	-0.0833	1994	183.2	-0.0508
1993	32.0	-0.0473	1994	133.8	0.0861	1991	216.5	0.2638
1999	32.1	-0.0450	2002	142.7	0.1895	1995	232.5	0.4143
2001	33.9	0.0059	2003	**155.9**	**0.3423**	1990	249.3	0.5725
1995	35.3	0.0476	2001	166.2	0.4616	1986	250.7	0.5858
1996	36.2	0.0707	1997	178.3	0.6013	1988	261.6	0.6887
1985	39.3	0.1597	1998	224.2	1.1338	2003	**274.6**	**0.8110**
1989	40.2	0.1849	1985	240.0	1.3166	1985	283.9	0.8993
1998	117.5	2.3931	1988	295.8	1.9635	2002	378.5	1.7915
1990	141.9	3.0898	1990	313.8	2.1722	1998	431.9	2.2953
Mean	**33.7**		Mean	**126.4**		Mean	**188.6**	
Stdev	**35.03**		Stdev	**86.29**		Stdev	**106.01**	
Std Error	**7.83**		Std Error	**19.29**		Std Error	**23.70**	

It can be seen from the above Table 7 that the months of April and May 2003 inflows indicated Above Normal inflows while the month of March showed anomalies that were the lowest in record. These predictions are yet to be compared with the true observations at a later time.

6.4 Predictions for SOND 2003 inflows into Masinga and Kamburu Dams

Figures 8a and ***8b*** present the SOND 2003 forecasts for Masinga and Kamburu Dams respectively. The predictions indicate near-normal inflows into these dams during the SOND 2003 season. The forecasted inflow anomaly for Masinga Dam was 0.4562 that is equivalent to 331cumecs thus the forecast have a tendency of slightly being in the above normal category. For Kamburu Dam, the tendency is towards Near-Normal to above (Figure 8b).

The ranked anomalies and actual amounts for the inflows into Masinga and Kamburu Dams for the SOND 2003 season are presented in ***Table 8***

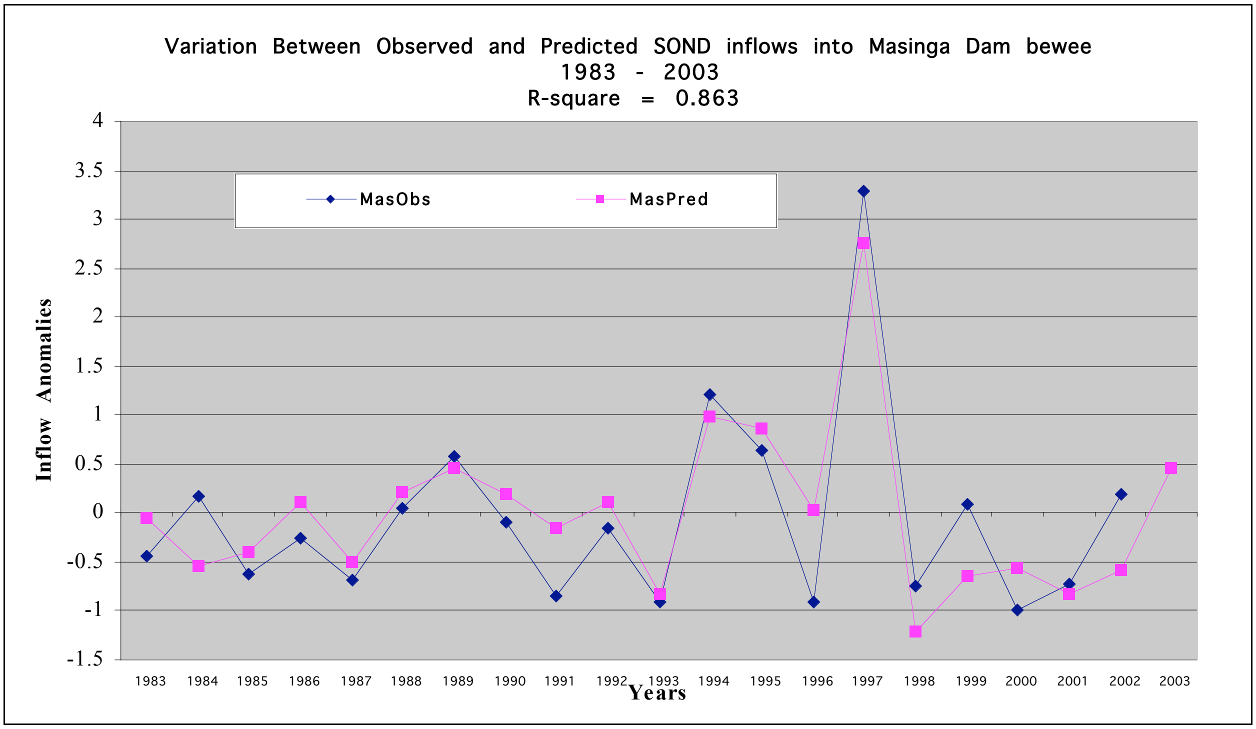

Figure 8a: *Comparison between Observed and Predicted SOND Inflow anomaly into Masinga Dam between 1983 - 2003.*

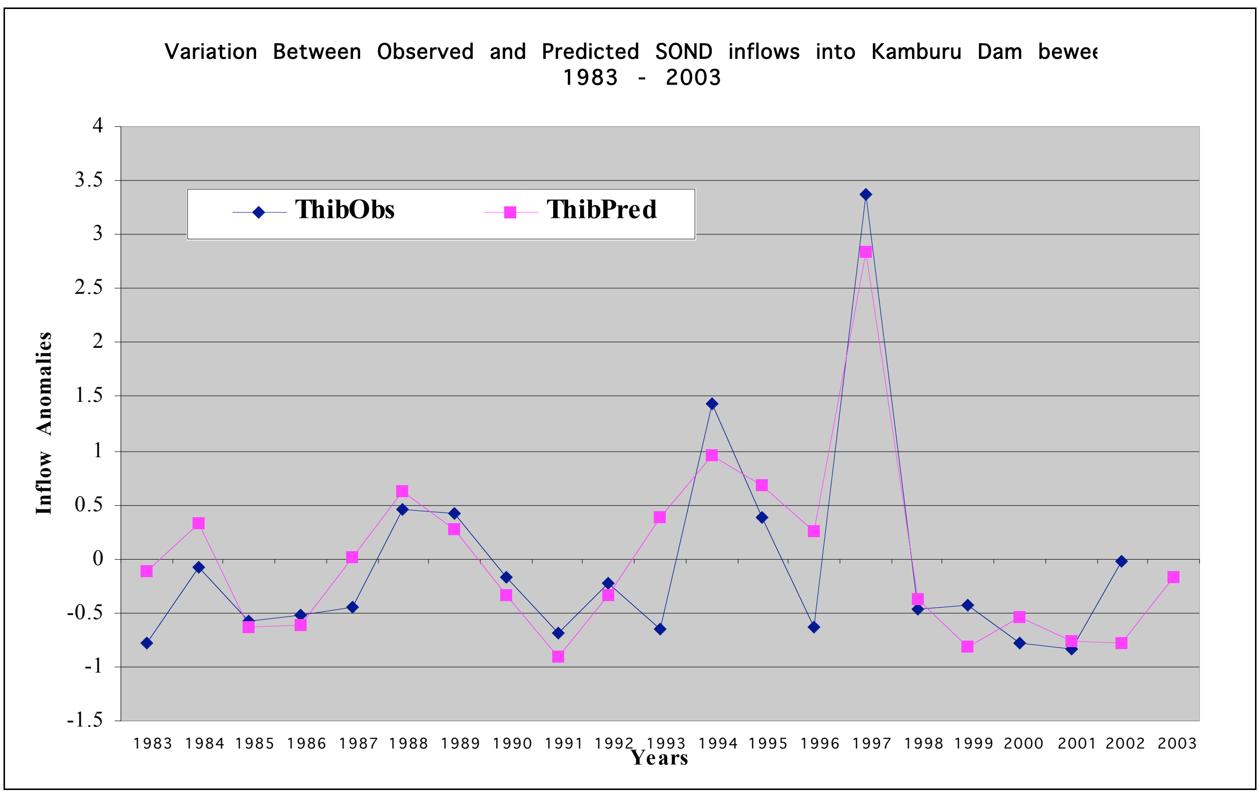

Figure 8b: *Comparison between Observed and Predicted SOND Inflow anomaly into Kamburu Dam between 1983 - 2003.*

Table 8: The Observed inflow anomalies from ranked forecasts for SOND 2003

Year	Masinga Observed	Masinga Predicted	Year	Thiba Observed	Thiba Predicted
2000	79.3	-0.9921	2001	22.2	-0.8423
1993	93.2	-0.9166	2000	27.1	-0.7764
1996	96.3	-0.8995	1983	27.4	-0.7726
1991	106.2	-0.8454	1991	34.3	-0.6809
1998	123.2	-0.7526	1993	36.1	-0.6569
2001	127.1	-0.7311	1996	38.3	-0.6276
1987	137.1	-0.6765	1985	42.0	-0.5785
1985	147.8	-0.6184	1986	46.3	-0.5214
1983	180.5	-0.4397	1998	50.2	-0.4695
1986	213.0	-0.2626	1987	51.5	-0.4522
1992	233.2	-0.1526	1999	53.7	-0.4230
1990	244.0	-0.0935	1992	68.3	-0.2289
1988	270.2	0.0494	**2003**	**70.7**	**-0.1675**
1999	278.0	0.0919	1990	73.0	-0.1665
1984	291.2	0.1640	1984	79.9	-0.0748
2002	295.5	0.1873	2002	83.9	-0.0221
2003	**331.6**	**0.4562**	1995	113.8	0.3758
1989	367.7	0.5817	1989	116.4	0.4104
1995	379.9	0.6480	1988	120.2	0.4609
1982	477.1	1.1784	1982	178.3	1.2331
1994	481.1	1.2002	1994	193.7	1.4378
1997	862.2	3.2797	1997	339.5	3.3757

7.0 Use of climate forecasts by KenGen

The climate information and prediction products are evidently very useful to KenGen Company mainly for the planning and management of hydroelectric power generation in Kenya. KenGen had the following success stories to make regarding the seasonal climate forecasts being issued by KMD/DMCN:

- Both the short and long term forecasts are increasingly being used by the company for planning and management of hydropower production and in particular for reservoir operations and water management.
- The Hydrologists working with KenGen are now able to appreciate the forecast given in tercile format. However, attempts are being made to translate these probabilistic forecasts into actual amounts as given in this study. Other attempts are also being made to provide KenGen with Benchmarks such as *Analogue Years* alongside the regular forecasts.

8.0 Conclusions

- The results from this study has indicated that the global SST anomalies have excellent predictive capabilities for streamflow forecasting in the Upper Tana River catchment at seasonal time scales.
- However, more work needs to be done along these lines to further improve the streamflow forecasting models.
- There is need for DMCN and KMD to continue working in partnership with the Hydropower sector in order to come up with tailored made products suitable for this sector

9.0 Recommendations

The following recommendations were deemed to serve as useful strategy in planning for future power supply in the country:

- There is an urgent need for the energy sector, particularly KenGen, to collaborate fully with Drought Monitoring Centre and Kenya Meteorological Department in the improvement of weather products and monitoring in the major power generating basins of Kenya (Tana/Turkwel);
- There is need for DMCN/KMD to provide shorter time scale climate forecasts such as daily, weekly and decadal forecasts to KenGen;
- There is need to set up sufficient rain-gauge stations around the Aberdares and Mt. Kenya areas since these are key catchment areas for the 7-Forks Dams. Dense station network are required that covers areas with "Kiambu, Muranga, Nyeri, Kirinyaga and Embu.

ANNEX A

Questionnaire On The Usage Of Climate Information To Your Organisation

1. Specify the methods through which your organisation receive climate information [Tick as appropriate]

Method	Yes	No
Fax	[ ]	[ ]
E-mail	[ ]	[ ]
Telephone	[ ]	[ ]
Meetings/Workshops	[ ]	[ ]
Internet Websites	[ ]	[ ]

2. How long in advance does your organisation receive the forecasted **CLIMATE** information?
Minimum .... [days, weeks, months]

3. How useful has this **CLIMATE** information been to your organisation? [Circle the most applicable]
   a. Very
   b. Somewhat
   c. Not at all

4. Briefly explain how the year-to-year and season-to-season climate variations (Impacts) affect the activities of your organisation.
   ....
   ....
   ....
   ....

5. What additional information, if any, do you think would help your organisation minimize the negative effects of the climate variability? [Specify]
   a. ....
   b. ....
   c. ....

6. What limitations or problems have you noted in the climate Information received by your organisation? [list]
   a. ....
   b. ....
   c. ....

7. Specify the type of climate information that would be most beneficial to your organisation and how long in advance of the period to be forecasted your organisation would like to receive this information?
   a. Type of information..
      How long in advance ....
   b. Type of information..
      How long in advance ....
   c. Type of information..
      How long in advance ....

8. Have your organisation made any use of the **above** types of information in decision-making? [Please specify]
   Type A..
   Type B..
   Type C. ....

9. What problems or challenges do your organisation face related to seasonal climate forecsts?
   a. ....
   b. ....
   c. ....

10. How accurate have past forecasts (i.e. whether the coming season rains will be above or below normal of the long-term average) been perceived by your organisation?
    (a) Very Bad
    (b) Not Bad
    (c) Good
    (d) Very Good

11. Briefly explain how your organisation has been using the results of the PAP project that was carried by DMCN in the recent past.
    ....………………………………………………...................
    ....…………………………………………………….

12. What would be the best way of presenting the climate forecast to your organisation? [Circle all that apply]
    a. Explanation in words
    b. Probabilities of possible outcomes
    c. Actual Amounts plus error margins
    d. Other (please specify)……………………………………………..
